Project Report: The Planetary Context of Biological Evolution: Molecular and Isotopic Approaches to Microbial Ecology and Biogeochemistry

Lead Team:	***Harvard University***
Project Title:	***The Planetary Context of Biological Evolution: Molecular and Isotopic Approaches to Microbial Ecology and Biogeochemistry***
Project Investigators:	***Roger Summons, Andrew Knoll***

Project Progress

Isotopic analyses of nucleic acids. At the time of the last report, Alex Sessions was completing his doctoral thesis and Ann Pearson was working at Woods Hole Oceanographic Institution (WHOI) as a postdoctoral research associate, obtaining molecular biological advice through collaboration with Dr. Katrina Edwards, a member of the resident scientific staff at WHOI. Almost within weeks, Sessions passed his final oral exam and transferred to postdoctoral status and Pearson decided (most sensibly) to accept the offer of an assistant professorship in biogeochemistry at Harvard. Her move dissolved our collaboration with Edwards and temporarily arrested our progress on analyses of nucleic acids. More recently, samples have begun to flow from Cambridge to Woods Hole. Specific analyses have yielded isotopic compositions for the 16S ribosomal ribonucleic acid (RNA) from *Cenarcheum symbiosis* and a bacterium growing in association with the sponge *Axinella mexicana*. A report summarizing the capabilities of this technique will be submitted for publication in the fourth quarter of 2002.

Bacterial fractionations of hydrogen isotopes. The collaboration between Sessions and Linda Jahnke (NASA/Ames Astrobiology group) led to an extensive paper describing the sources of H used in biosynthesis of lipids by the aerobic methanotroph *Methylococcus capsulatus* Bath and the isotopic fractionations associated with the biosynthetic pathways. A revised version of that manuscript has now been accepted for publication in *Geochimica et Cosmochimica Acta*.

Hydrogen isotopic analyses of Australian oils. Sessions and Roger Summons (a member of the staff of the Australian Geological Survey Organisation at the time of the last report, now a member of the faculty at MIT) have completed analyses of an extensive series of oils from Australia. The results suggest that hydrogen isotopic compositions of sedimentary

hydrocarbons are minimally affected by diagenetic processes and can be used to resolve mixtures of sedimentary compounds with distinct sources.

Molecular Organic Geochemistry. New team member Roger Summons conducts research on the chemical and isotopic characterization and biogeochemical significance of lipids from cultured microbes, environmental samples and their fossil analogues in ancient sedimentary environments. In collaboration with Linda Jahnke (NASA Ames) and a research group at the University of Regensburg, Germany (Prof Dr Karl Stetter, Dr Robert Huber, Dr Harald Huber and Dr Manuela Baumgartner and their graduate students), he is currently analyzing the lipids of a number of new isolates of thermophilic and hyperthermophilic bacteria (Aquificales new sp., *Thermovibrio ruber*) and archaea (e.g. *Ignicoccus* sp., *Nannoarchaeum equitans, Methanococcus* sp.). *Ignicoccus sp.* and *Nannoarchaeum equitans* represent new phyla, and their physiologies are unknown. Through this work, Summons and colleagues have greatly extended our understanding of the variety and complexity of extremophile lipid biosignatures. In complementary studies with Kathleen Londry of the University of Manitoba, he is re−examining the carbon isotopic fractionation associated with methanogenesis by *Methanosarcina barkerii* grown on different carbon sources and under different conditions. Preliminary research has begun on organic−rich, low maturity sediments that span both the Precambrian−Cambrian (Oman) and Permo−Triassic (Australia) boundaries. The aim of this aspect is to search for biomarkers that might be diagnostic for biogeochemical processes, such as methanogenesis and methane oxidation or productivity collapse associated with negative carbon isotopic excursions. In complementary studies of ancient hydrothermal environments, collaborating with Malcolm Walter of Macquarie University and colleagues at Geoscience Australia, he has submitted a paper on geochemical signatures for the hydrothermal alteration of organic matter associated with the formation of a sediment−hosted lead−zinc sulfide deposit. The polycyclic aromatic hydrocarbon (PAH) and other hydrocarbon distributions in this deposit reflect a thermal halo, and they can be used to map the source and cooling profile of hydrothermal brines that moved through the sediment system and created the mineralization.

Highlights

- Alex Sessions has developed and demonstrated techniques allowing the preciseanalysis of carbon−13 in samples of nucleic acids as small as 3 nanomoles C (H 100 ng RNA).
- Roger Summons and colleagues have made significant progress in elaborating the lipid biosignatures that are diagnostic for extremophile Bacteria and Archaea.
- Analysis of hydrocarbon profiles has led to the development of a new model for the hydrothermal mineralization process that resulted in the Mesoproterozoic McArthur Basin base metal sulfide deposit.

Roadmap Objectives

- ***Objective No. 1:*** Sources of Organics on Earth
- ***Objective No. 2:*** Origin of Life?s Cellular Components
- ***Objective No. 5:*** Linking Planetary Biological Evolution
- ***Objective No. 6:*** Microbial Ecology
- ***Objective No. 7:*** Extremes of Life
- ***Objective No. 8:*** Past Present Life on Mars
- ***Objective No. 14:*** Ecosystem Response to Rapid Environmental Change

Mission Involvement

*Mission Class**	*Mission Name (for class 1 or 2) OR Concept (for class 3)*	*Type of Involvement***
2	MSR	Planning support

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long−lead future mission / societal issues (e.g., far−future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co−I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

Summons is a member of Mars Exploration Payload Analysis Group (MEPAG) and the Astrobiology Science Strategy Group (SSG) under the chairmanship of Jack Farmer to provide an Astrobiology perspective and advice on molecular biosignatures that might be relevant in planning for a Mars Sample Return mission.

Cross Team Collaborations

Dr. Kai Hinrichs, a member of the scientific staff at WHOI and previously listed as a collaborator on this report, is *still* a collaborator but is now one of the Co−Is of the new Astrobiology team based at the University of Rhode Island. With Dr. Hinrichs, Hayes is working on the analysis of individual biomarkers from the Lost City hydrothermal field. Summons is also collaborating with

Hinrichs on the development of new mass spectrometric methods for the direct analysis and identification of intact lipids of extremophiles.

Collaboration with Linda Jahnke and Tsegereda Embaye of the NASA Ames Team has led to the identification of a new suite of lipid biomarkers for thermophilic methanogens. This team has also continued a study of cultured

cyanobacteria and related environmental samples for information of their diagnostic biomarkers and environmental controls on lipid biosynthetic pathways.

Collaboration continues with Jennifer L. Eigenbrode and Katherine Freeman of the Penn State Team. Jennifer is studying Archean and Early Proterozoic sediments of the Pilbara Craton for the presence of diagnostic molecular biosignatures in rocks of different lithologies.

Collaboration with members of the Australian Centre for Astrobiology has resulted in an improved understanding of the environment of deposition and a new model for the formation of a Mesoproterozoic metal sulfide mineralization.